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Eco-energy and urbanisation: messages from birds about wind turbine proliferation

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By 2010, 51% of humans live in cities, rising to 70% by 2050. Energy consumption increases exponentially with the proportion of the populace living in conurbations. Fossil fuels supply 85% of global human energy, yet many acknowledge the need to switch to renewable sources, especially given recent concerns over nuclear power safety. Finland will consume 14% more electrical energy by 2035, plus another 14% were the country to switch to electric cars. Such increased demand could be met by 2730 × 2.3 MW wind turbines (covering 1050 km^2 of sea). Wind turbines may cause displacement from bird feeding areas, barriers to movement, modifications to habitats and collision mortality. Effective implementation of Strategic Environmental Assessments and Environmental Impact Assessment should guide sensitive positioning of wind farm development to avoid conflicts with avian populations. Experiences from existing developments, combined with modelling approaches, must ensure attempts generate renewable energy from wind do not impact unacceptably upon local nature.

Urbanisation

Globally just over half (50.5%, 3.5 billion people) of us live in cities; in North America, just 18% of folk now live outside of major conurbations (United Nations 2009). The rush to live in dense proximity amongst other people is one of the most marked phenomena of our time: current predictions estimate 6 billion will live in cities by 2050 (70% of the Earth's people compared with just 3% in 1800, United Nations 2009). And little wonder: to be tied to a subsistence existence or to rural agriculture, with unpredictable weather and hence erratic food supply, limited income and little prospect of self improvement beyond basic subsistence, compares very unfavourably with the glittering attractions of the metropolis.

As if human beings were not causing enough damage to our planet and environment, increasing evidence shows that our rush to aggregate is also a process that enhances our rate of energy consumption. The reasons why per-capita consumption of energy in cities is substantially greater than in equivalent rural areas are highly debated, but the explanations are likely to be many and varied. Industrialisation associated with urbanisation demands energy, although whether that consumption is any greater than equivalent dispersed, small-scale, potentially inefficient rural production per unit is a matter of debate. Production economies of scale are invariably severely adversely compromised energetically by their associated transport energy costs (for import of raw materials, export of manufactured goods and a regular supply of workers to the factory gates, Jones 1991). Furthermore, the associated workforce creates a consumer reliance on increasingly remote agricultural supplies to feed, clothe and maintain factory workers (Jones 1991). Peri-urban agricultural systems, too, must become increasingly mechanised and energy-consumptive to produce and transport burgeoning subsidies to their consumer markets in the cities (Maxwell *et al*. 1999, Bojaca and Schrevens 2010), also adversely affecting biodiversity (Vermaat *et al*. 2007), although help may be at hand with new plans to green cities by local food production (e.g. van Timmerman *et al*. 2004, Moustier 2007, Ashlee and Kishnani 2010, de Bon *et al*. 2010). Cheap city housing and buildings consume large amounts of aggregate, bricks and concrete which also consume disproportionate amounts of energy (and in the case of concrete using a process that itself creates carbon dioxide; Parikh and Shukla 1995). Urban dwellers are increasingly exposed to climate change from greenhouse gas induced radiative forcing, and local "urban heat island" effects, not least because the most rapid urbanisation is occurring in the warmer regions of the planet, notably the Middle East, East Africa, the Indian subcontinent and China (McCarthy *et al*. 2010). This carries an increasing cost to maintaining habitations and work places comfortably cool during seasons of high temperatures, as in China where air conditioning energy consumption is increasing dramatically (Li and Yao 2009). But whatever the mechanism driving this relationship, there is some consensus that energy consumption per capita increases exponentially with the proportion of the population living in cities (e.g. Parikh and Shukla 1995, Imai 1997). The more we flock to cities (and the rate at which this is happening is also increasing at the present even here in the Nordic Countries), the even greater our consumption of energy per head (Fig. 1). As many countries exceed 60% urbanisation of their populace, so the exponential nature of the relationship drives up the demand for energy, notwithstanding the fact that in many western and other urbanising states, the average carbon emissions of city dwellers may actually be less than those of the non-urban populace (e.g. Satterthwaite 2008, Dodman 2009).

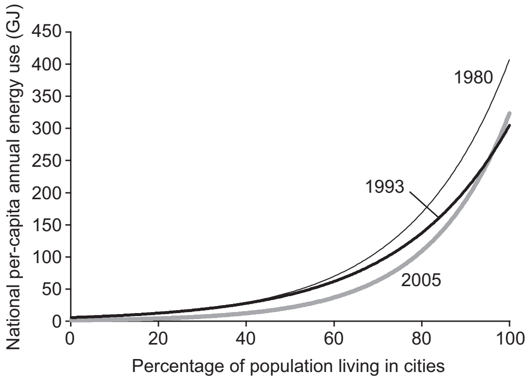

Fig. 1. Relationship between energy consumption per capita (C in GJ per year) and the percentage of a nation's populace that live in cities (U), based on 1980 and 1993 data presented in Imai (1997) and a new analysis of available data as of 2005 (data sources: USEIA 2005, and UN 2009, best fit exponential regression model has the equation $C = 1.409e^{5.437U}$, r_{186} = 0.58, $p < 0.05$). Since many countries have 75% or more of their populations already dwelling in conurbations, it is evident that relatively small changes in this proportion greatly affect energy consumption patterns.

If we are to avoid costly transport of carbon fuels to city distribution points, these demands are likely to be increasingly met by electrical energy, which coincidentally applied to city transportation can improve local air quality, reduce carbon dioxide emissions and bring human health benefits. Although electric trams and trolley buses are a feature of many cities around the world, such technologies are seeing a renaissance. Electric busses are in mass production in China (Zhongtong Bus Holding 2010), are in use in California (Reuters 2010) and planned in many cities such as Leipzig and Montreal; the Japanese Government has funded electric taxis in Tokyo (Japan Times 2010). Cities are increasingly investing in no-emission transport systems which place greater reliance upon electrical energy supply to solve problems of pollution, carbon dioxide emissions and latterly public concerns over nuclear power safety in the light of the Fukushima incident.

It is clear that cities present both problems and solutions to sustainability challenges of an increasingly urbanized world (e.g. Grimm *et al*. 2008), but the fact remains that as countries concentrate a greater proportion of their population into urban areas, the demand for energy will increase at a greater rate than if the population was maintained as at present. Given this premise of increasing future demands for energy generally, the remainder of this review addresses the particular issue of electrical energy consumption and existing eco-energy solutions to this energy supply crisis, concluding with a discussion of how our renewable energy solutions may be compatible with avian conservation, since bird species figure prominently in environmental impact assessments of renewable energy sources such as windfarms.

Energy consumption and electrical energy generation

Most of the world's energy comes from three primary fossil fuels, oil, coal and gas, which in 2006 accounted for 36%, 27% and 23% of all energy consumption, respectively (USEIA 2008). Although energy from oil is largely spent in transportation, globally, electric utilities generate 41% of the world's electricity from coal, 20% from gas, 16% from hydro sources, 15% from nuclear energy and 6% from oil (data from 2007, IEA 2010a). In the US, 46%–50% of electricity is supplied from coal and 40%–48% from gas (based on 2008 and 2009 data, USEIA 2010a), but coal supplied over 80% of electricity needs in South Africa (94% of consumption), Poland (93%) and China (81%, data from 2007, IEA 2010b). Hence, substantial saving in the burning of coal to generate electricity could be made by adapting to renewable supplies. For the purposes of this article, I take eco-energy as being synonymous with "renewable energy", that is energy made available for us to exploit which is naturally replenished, renewable in the sense that it comes from natural resources such as sunlight, wind, rain, tides, and geothermal heat which are generally not limited by depletion effects in any short term time scale (i.e. centuries).

Projected expansion in energy demands and how to meet these

Not withstanding the exacerbation of energy demand associated with urbanisation, current forecasts are for a 84% increase in energy consumption in the non-OECD countries from 2007 to 2035 and 14% increase in energy use by OECD nations over the same period (USEIA 2010b), most of the demand for which is predicted to be met by our traditional sources of fuel in the form of oil, coal and natural gas which together supply ca. 85% of our current energy consumption (USEIA 2010b). If we are serious about weaning ourselves off fossil fuels, we need to start thinking very seriously about how this may be possible.

One contemporary area of potential reduction in fossil fuels is associated with the shift from petrol driven private vehicles to electric cars. As of November 2010, there are plans for the imminent launch of at least eight production-line electric cars world wide, with numerous other designs in the pipeline searching for development backing. Most producers of electric cars have been disappointed at the lack of demand from the public around the world following launches of prototypes, but it could well be that such competition will force prices down and create a more buoyant demand amongst consumers. If this were to be the case, there could be a sudden surge of demand and potentially a rapid transfer from petrol powered to electric cars. Most current electric cars require an equivalent of 10–25 kWh to power a vehicle for 100 km of regular driving (United States Department of Energy Office of Energy Efficiency and Renewable Energy 1999, Idaho National Laboratory 2006). If we take Finland as a representative European nation of just under 5.5 million inhabitants (Statistics Finland 2009a), driving 2.8 million cars a total of 53.4×10^9 km each year (Statistics Finland 2009b), that level of efficiency conversion equates to electricity consumption of between 5.3 and 12.2 TWh per annum to power a domestic electric car fleet equivalent to that of the current number of petrol powered cars. Since the number of kilometres driven by Finnish cars has changed little over the last 3–4 years, we assume negligible growth in this statistic before 2035 for the purposes of these calculations. Considering the current consumption of electricity in Finland in recent years (ca. 80.7 TWh in 2009, Statistics Finland 2010), the increased electricity consumption should equate to an extra 12

TWh per annum by 2035 (based on the USEIA projected average 14% expansion in demand), with a maximum increase in consumption of a similar order of magnitude again to account for domestic electric car consumption. To give some idea of the necessary eco-energy supply required to meet such an expansion in demand, it should be remembered that the new Finnish Olkiluoto-3 reactor is built to provide 1.6 TW and that very first production scale offshore wind farm at Horns Rev (off the west coast of Denmark) comprised 80×2 MW turbines produces an estimated 0.6 TWh per annum (Dong Energy 2002). The second such wind farm constructed nearby at Horns Rev, completed this year, comprises 91 2.3 MW turbines, each 114 m high, covering an area of 35 km^2 and costing 500 000 000 Euros (Dong Energy 2010). It is expected to produce 0.8 TWh per annum, so on this basis, it would be necessary to erect 2730 2.3 MW wind turbines in Finnish waters (assuming similar wind characteristics), covering an area of some 1050 km^2 to fulfil Finland's projected expansion in electricity consumption, including supporting a full transfer of domestic cars from fossil fuels to electric vehicles by 2035.

Renewable energy is highly unlikely to meet our immediate energy needs nor in the longer term to contribute substantially to reducing our fossil fuel consumption. However, there is no doubt that many governments currently see it as a way of at least attempting to ease our addiction to historically stored carbon. Unfortunately, the costs of electricity generation are complex and their unbiased estimation hard to derive. The nuclear industry are keen to show that the levelised costs of electricity per MWh generated by their plants make this by far the cheapest option (IEA/NEA 2010), although of course anti-nuclear lobbies will argue over the costs of waste disposal and decommissioning. However, most agree that the competitiveness of renewable energies varies regionally throughout the globe, dependent upon many associated factors. There is no doubt that in some parts of the world, notably in North America, costs associated with the generation of electrical power from onshore and offshore wind turbines compare very favourably with contemporary fossil fuel plants.

Eco-energy and the current pre-eminence of wind power

As of 2006, about 18% of global final energy consumption came from renewables, with 13% coming from traditional biomass, which is mainly used for heating, and 3% from hydroelectric generation. So called "new renewables" (small hydro, modern biomass, wind, solar, geothermal, and biofuels) accounted for another 2.4% and are growing very rapidly (REN21 2007). The share of all renewable sources to electricity generation was around 24% in 2008, with 20% of global electricity coming from hydroelectricity and 3% from wind power (REN21 2009)

Not only is the wind the next most important source of renewably generated electrical energy after hydro-electricity generation (which has limited utility and is not necessarily environmentally benign), but exploitation of wind power is currently growing at the rate of 30% annually. In 2009, the installed global capacity was estimated at between 157.9 GW (REN21 2009) and 159.2 GW (WWEA 2010), mostly in Europe, Asia, and the United States, with China and many Asian states showing considerable enthusiasm for the technology.

Although photo-voltaic electricity sources contributed 6.9 GW to world electricity consumption in 2008 and there is considerable interest in large solar thermal power stations (for example in the USA and Spain), investment and development in other technologies have not lifted these alternative sources of renewable technology to the point where there are being widely adopted. These technologies are likely to become more prevalent in the near future, especially in areas where a relatively constant supply of cloudless sunshine offers a profitable and consistent source of such energy. With these exceptions, at present, most other renewable energy sources have not developed to a level where they present any significant hazard to the environment at present, even if they may do so in the future. Hence, although many of these alternative renewable energy sources may rapidly contribute to electricity generation to meet the needs of our increasingly urban population in the future, it seems more appropriate to concentrate on the effects of wind power on avian populations because it is likely to be the predominant form of renewable energy that most birds are likely to encounter in their lives, at least in the foreseeable future.

Power generation from wind

We are not the first human generation to harness wind as a source of power. The ancient Egyptians were using sailing ships prior to 3200 BC (Ruiz 2001) and by the 1st century AD, Hero of Alexandria was exploiting a wind wheel to power an organ (Drachmann 1961, Lohrmann 1995). By the 19th century, the skyline of the Netherlands boasted 9000 windmills which had revolutionised agriculture (Hoeksema 2007) and powered mills that could grind, saw, hammer and make paper, indeed wind could power any process that required mechanical movement (Stokhuyzen 1962). However, there is no denying the current global enthusiasm for generating electrical energy from wind power, with world capacity reaching 159.2 GW by 2009, after a doubling every three years (WWEA 2010). This equates to a delivery of 340 TWh each year, approximately 3% of global electricity consumption (WWEA 2010). By the end of 2009, almost 75 GW of power capacity was installed throughout Europe, almost two thirds in Germany, Spain and Portugal, constituting 9% of installed capacity in these states (EWEA 2010). Denmark now derives 18% and Spain 17% of electricity supply from wind power (DEA 2009, REE 2010), with wind power meeting a record 39% of Ireland's total electricity consumption on 31 July 2009 (Kanter 2009). By the end of 2007, 1% of electrical wind energy was supplied from offshore installations (1000 MW capacity in Denmark, Ireland, the Netherlands, Sweden and the UK GWEC 2009). However, many states have an eye to developing offshore wind resources where wind profiles are often very favourable (capturing up to 50% more energy than onshore because of efficiencies in exploiting higher wind speeds with less associated turbulence, Henderson *et al*. 2002) and complaints from NIMBY ("not in my back yard") protesters are fewer and confined to specialist interest groups such as fishermen, shipping interests and the military.

Wind turbines are therefore here to stay, as they represent the frontline in the development of renewable technology as far as the immediate future is concerned. The initial engineering and economic challenges have largely been overcome and the technology has become standard, so the question is, if we begin to cover our landscapes (both on land and offshore) with these turbines, what will be effect on the environment? Because birds share the aerial environment with the rotating turbine blades, have a particular resonance with the public and are protected under a variety of international legal instruments, laws, agreements and conventions, there have been particular concerns about the impacts of wind farms on avian populations. But how much do we know and how much more do we need to find out?

How do wind turbines affect or impact upon avian populations?

It is generally accepted that wind turbines affect birds in three major ways (Fox *et al*. 2006a):

1. Behaviourally, by their avoidance of the vicinity of the turbines as a behavioural response to an aural or a visual stimulus (either (i) by causing displacement from favoured foraging areas, equivalent to effective loss of habitat or (ii) displacement from preferred routes of movement, the so-called "barrier effect").
2. Physically, through destruction, modification or creation of habitat associated with turbine/infrastructure construction.
3. Demographically, as a result of mortality from physical collisions with the superstructures.

Much focus has been placed on the collision rates because these have a direct demographic impact on populations, through additional mortality above that caused by other factors. However, avian avoidance of turbines may constrain access to profitable feeding areas as may modifications to habitat caused by construction. This would result in extra energetic costs of extended movement and lost feeding opportunity, which could equally adversely affect fitness of individuals (through reduction in breeding output or ultimately death) in a way that could also contribute to change in population size. In the early stages of wind power development, many studies highlighted the potential impacts of these factors (Langston and Pullan 2003, Barrios and Rodriguez 2004, Garthe and Hüppop 2004), but the reality has been that whilst it is relatively simple to show effects of wind turbines on birds (e.g. measure the extent of avoidance flights and even count numbers of mortality events) it has proved difficult to gather sufficient data to truly demonstrate impacts on populations. This has largely been because of serious short-comings in methodologies applied to studies, which are generally too short-term to enable statistically robust analysis of effects on bird populations (Hötker *et al*. 2006). Furthermore, these studies rarely, if ever, involve classic Before-After Control-Impact designs that gather baseline data prior to construction and contrast patterns at the construction and a control non-intervention site post erection of turbines (Guillemette and Larsen 2002, Hötker *et al*. 2006, Stewart *et al*. 2007). A lack of recommended standard practice for such studies has meant a diversity of approaches to the assessment of impacts on avian populations that make it difficult to undertake effective comparisons and syntheses from the available data. Finally, studies of the effects of individual wind farms on birds are rarely published outside of the "grey literature", and often not at all if consenting does not depend on post-construction reporting.

Avoidance (effective habitat loss)

Not surprisingly, therefore, despite agreement that wind farms are likely to have adverse effects on bird populations, there has been little published evidence of statistically significant evidence of negative impacts on breeding birds (Hötker *et al*. 2006). Some studies do conclude negative effects (especially on Lapwings *Vanellus vanellus*, e.g. Gerjets 1999), but the only clear evidence of significantly lower frequencies of occurrence close to the turbines, after accounting for habitat variation, was found amongst 7 out of 12 upland breeding species with equivocal evidence of turbine avoidance in a further two (Pearce-Higgins *et al*. 2009). Non-breeding birds that use areas close to turbines for feeding do show more signs of avoidance, for instance Hötker *et al*.'s (2006) meta-analysis showed more negative than positive effects of wind farms amongst largely grassland habitats in Europe, especially amongst herbivorous geese and ducks (bean goose *Anser fabalis*, white-fronted goose *A. albifrons*, greylag goose *A. anser*, barnacle goose *Branta leucopsis* and wigeon *Anas penelope*) and invertebrate feeding waders (lapwings and golden plovers *Pluvialis apricaria*). These birds may avoid turbines by up to 500 m, but it is difficult to determine whether such effective loss of habitat ultimately affects population size. Furthermore, recent evidence suggests that after 10 years, pink-footed geese *Anser brachyrhynchus* at least may modify their responses, at two different sites reducing the avoidance distance and feeding between turbines where formerly this was not the case (Madsen and Boertmann 2008). Offshore, there is evidence that marine birds may be displaced from foraging areas as a result of human disturbance (Kaiser *et al*. 2006, Schwemmer *et al*. 2011) including the erection of turbines (Larsen and Guillemette 2007), but common scoter *Melanitta nigra* that formerly were rarely seen flying or settling on the open sea between the turbines of the Horns Rev off SW Denmark in the three years post construction, were commonly reported between the turbines five years after turbine erection (Fox *et al*. 2006b and unpubl. data). In this case, it was impossible to state whether changes were due to habituation of individuals, new birds learning new traits, or if changes in food supply were responsible for distributional changes. By contrast, studies at Nysted in southern Denmark have shown statistically significant reductions in wintering long-tailed duck *Clangula hyemalis* numbers only in the wind farm (based on comparison of three years of base-line data with post construction surveys; I. K. Petersen unpubl. data). Mechanisms behind such reductions in numbers are also not understood; they could be associated with food supply, behaviour or the responses of individuals to moving objects such as turbines, but the net effect is lower densities of birds post construction compared to pre-construction, despite increases in numbers outside the wind farm.

Furthermore, divers (mostly red-throated *Gavia stellata*) are almost never seen within the wind farms at Horns Rev and Nysted, although densities generally were low even prior to windfarm construction (Fox *et al*. 2006b). It continues to be far from clear what the causes of these "avoidance" or "displacement" patterns might be, nor if the organisms concerned are likely to change their behaviour over time. Nevertheless, experiences with, for example, the geese and scoter over longer timescales underlines the need for studies extending over more than one season to inform upon inter-annual variability, species- and site-specific responses and to assess the probability of habituation or other modifications to behaviour and distribution where demonstrable displacement has been proven.

The question also arises, how important is displacement from ideal feeding distributions to individuals and ultimately to the populations from which they are drawn. In the case of the long-tailed ducks at Nysted, the numbers of individuals "lost" from the windfarm site post construction amounted to a maximum of a very few hundred at peak times, which considered in the light of a flyway population amounting to 4.6 million individuals (Wetlands International 2006) with abundant feeding opportunities elsewhere along the flyway could be interpreted as being unlikely to have an effect on the population as a whole. However, it is possible to conceive that where habitat may be limiting, or indeed where wind farms are constructed in areas where birds are very heavily reliant on the areas lost to turbine construction for their food supply, such habitat loss may assume far greater significance. For instance, recent modelling of the combined effects of both habitat loss and collision rates amongst a sedentary population of hen harriers *Circus cyaneus* on Orkney (islands off the north coast of Scotland) showed that the greatest impacts on the population size resulted from loss of feeding habitat associated with turbines located within 1 km of hen-harrier nest sites (Masden *et al*. 2010a). Indeed, the removal of collision mortality from the model highlighted that the majority of turbine impacts were associated with habitat loss (Masden *et al*. 2010a). This exercise underlines the potentially important impacts of habitat loss that may not be intuitively evident, reinforcing the importance of modelling in the effective assessment of relative costs of habitat loss to avian populations when collision mortality may be the source of more directly evident population impacts.

Avoidance (barrier effect)

Very little scientific attention has been paid to determining whether wind turbines act as barriers to bird movements, especially on land. Very few designed experiments have been undertaken to compare whether birds that flew a particular bearing and height trajectory prior to construction of wind turbines have shown changes in that orientation post erection. The use of conventional navigation radar to determine flight direction and altitude of flying birds has become widespread in impact studies at offshore windfarms (M. Desholm unpubl. data) but many of the results continue to be published in the grey literature or are subject to being commercial in confidence. We lack robust meta-analyses of such studies comparing pre-construction predictions with post-construction observations. A radar study of migrating common eider pre- and post-construction at the Nysted wind farm in southern Denmark showed that the majority of birds approaching the wind farm at 1.5–2 km avoided flying between turbines (Desholm and Kahlert 2006). An analysis of these deflections showed greater curvature in migration routes taken post construction and within 500 m of the outermost turbines. This disturbance displacement caused individuals to fly an additional 500 m, trivial in the context of the total 1400 km flight of the overall migration episode and therefore likely of little energetic consequence (Masden *et al*. 2009). More serious would be if breeding seabirds provisioning young were deflected by turbines whilst commuting between breeding colonies and feeding grounds (*see* Langston *et al*. 2010), although the energetic consequences of this varied considerably with body mass and provisioning rates (Masden *et al*. 2010b). One major problem associated with a meta-analysis of reported studies is that it is not always clear if reactions/lack of reactions to wind farms are reported equally, but by far the majority of reports for 81 species suggest effects (Hötker *et al*. 2006).

Collision rates

Bird collisions with turbines are highly contentious, but the situation is not helped in any way by the lack of well designed studies. Critical is the ability to unequivocally detect an avian collision event, which is compromised by the need for proxy measures, such as corpse searches below turbines, which require controls for disintegration of avian bodies and the scavenging activities of predators. Difficulties are compounded by the fact that many birds migrate under cover of darkness and corpse searches at sea are impossible. Despite considerable discussion of the topic, there remain very few published well-designed studies that unambiguously present collision rates at terrestrial wind turbines. Reported collision rates have varied between none and more than 50 collisions per turbine per year (e.g. Table 9 in Hötker *et al.* 2006), but obviously the rate varies with factors such as habitat, bird densities and species vulnerability, so generic averages are not helpful to assessing specific risk or population impacts. Situations with high rates of collision are those associated with aggregations of birds and high traffic, as in the case of tern *Sterna* spp. colonies (e.g. Everaert and Stienen 2007), or particular conditions under which birds are vulnerable (e.g. soaring raptors near mountain ridges in North America and Spain Erickson *et al.* 2001, Barrios and Rodriguez 2004). It is also important to reflect that some bird species are more sensitive to turbine induced mortality than others, relative abundance and demographic sensitivity both influencing population level impacts of a given number of casualties (Desholm 2009). It was concluded that even where passerines might be present in high numbers, these may represent insignificant segments of very large reference populations that, from a demographic point of view, are relatively insensitive to wind turbine related adult mortality. In contrast, in long lived species, such as birds of prey, the capacity to replace lost adult birds is much less and overall abundance low, making overall population size highly sensitive to even modest changes in annual survival. In the US, apprehensions about adverse effects of badly sited wind turbines were confirmed by experiences from the first large-scale wind farm at the Altamont Pass in California, where ca. 5000 wind turbines have been responsible for the deaths of hundreds of raptors per year since their construction. Protected species such as golden eagles *Aquila chrysaetos* are among the species affected (Orloff and Flannery 1992, 1996). Due to high mortality of raptors, there has been no further extension of this wind farm and overall the development of wind energy in the USA slowed down almost certainly as a result of this extraordinarily bad experience. The unfortunate deaths of hundreds of griffon vultures *Gyps fulvus* per year in Spain, a species numbering ca. 8100 pairs which is not robust to such losses has also been a warning of how badly things can go wrong if potential collision losses are not predicted by adequate Environmental Impact Assessment (EIA, SEO 1995, Lekuona 2001). Most recently, 26 wind turbine casualties amongst white-tailed eagles *Haliaeetus albicilla* on the Norwegian island of Smøla in just three years following construction is also clearly not an example of best practice (Kuijken 2009). On the other hand, where birds show strong avoidance responses to individual turbines, the risk of collision is much reduced and can be modelled and impacts predicted. Using stochastic collision models, based on data from surveillance radar and thermal imaging videometry, Desholm and Kahlert (2007) predicted only 47 out of over 235 000 common eiders *Somateria mollissima* passing the Nysted offshore wind farm would collide with the turbines each year (0.02%) because of the active avoidance behaviour shown by the species at multiple levels. Monitoring suggested that the collision rate was in fact less than this, confirming that costs associated with avoidance by some bird species would be compensated by low collision risk mortality.

Avoiding trouble in the first place

The key issues relating to avian interactions with wind turbines, like many other aspects of the planning process, lie in the effective implementation of environmental impact assessment procedures. European legislation theoretically requires Strategic Environmental Assessments

(SEAs) of national wind farm programmes and EIAs for individual projects likely to affect birds (Fox *et al*. 2006a). SEAs require extensive mapping of bird habitats and distribution densities to define breeding and feeding areas of importance and sensitivity, as achieved on a national scale for Scotland (Bright *et al*. 2008). Use of extensive large scale weather, military, and air traffic control surveillance radar is recommended, to define areas, routes and behaviour of migrating birds, and to determine avian migration corridors in three dimensions. EIAs for individual wind turbine developments should define the key avian species present; as well as assess the hazards presented to birds in terms of avoidance behaviour, habitat change and collision risk, for example using small scale surveillance radar verified by visual confirmation of species contributing radar tracks to define three dimensional birds movements in the vicinity of the proposed wind farm. It is self evident that the planning process should guide avoidance of mountain ridges (especially for soaring raptors and other large-bodied migrants), water bodies, wetlands and woodlands that attract birds, migratory corridors, river systems, mountain valleys and passes, coastal spits and peninsulas that funnel or concentrate migrants, as well as all sites with some level of nature conservation designation or protection for special concentrations or species. Illumination of turbines, both on land but especially at sea for safety and navigation purposes, has not been adequately studied with regard to the potential for permanent lighting to attract especially night-migrating birds during darkness, but all the evidence suggests that small discrete flashing lights are more likely to reduce collision probability than most forms of continuous white lights and especially floodlit illumination (Evans *et al*. 2007, Gehring *et al*. 2009). We also need to be better able to determine the cumulative effects of not just one wind farm, but the consequences of several wind farms constructed along the length of an avian flyway, as well as the interactions of these with all the other pressures from human development on waterbird populations. Such assessments are required under EU legislation, but these requirements are rarely fulfilled, despite increasing knowledge (Masden *et al*. 2010c)

Concluding remarks

Urbanisation is already putting pressure on urban ecosystems and the birds that resort to cityscapes, but the expanding thirst for energy created by the process of urbanisation requires we find quick fixes to our quest for sustainable electricity generation. We cannot ignore the effects of climate change and the effects that this is having on our native avifaunas, so if we cannot reduce demand, we have to accept the need for elevated energy generation and search for renewable energy sources to meet that demand. Many feel that wind energy offers a tried and tested, reliable technology that is environmentally relatively benign. The information briefly reviewed here suggests that our projections for increases in future electricity consumption, even in a country like Finland, may underestimate the demand in coming decades, because of our concern for reducing carbon dioxide emissions. Meeting that demand in a fashion that reduces our dependence on fossil fuels to generate energy will require many more innovative solutions than we currently have at our disposal. The most likely development in the sphere of renewable energy generation is through increasing exploitation of wind power, because it is a ubiquitous source and we already have the production systems geared to deliver such renewable energy at more or less known costs to the consumer and the environment. Sensitive positioning of wind farms can avoid the serious problems caused by large numbers of long-lived birds associating with wind developments situated in areas where construction of wind turbines can now be seen as ill-advised, given the subsequent death rate of sensitive species. As outlined above, we are developing better tools to predict not just the effects of wind farms (e.g. displacement or collision rates) but their impacts on population change to make informed choices about where to establish wind farms and reduce their impacts, we are even able to use observations of avoidance behaviour shown by birds to turbines to inform on optimal windfarm design, since the geometry of windfarms can affect the likelihood of birds coming near to, or indeed passing safely between, turbines (Masden *et al*. 2010d). Our challenge continues to be to use the right tools and planning constraints to ensure that our attempts to exploit renewable energy do not come at unacceptable costs to nature and to ensure that we accumulate existing experiences to improve our ability to predict these impacts.

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